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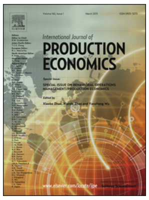

Variable neighborhood search for the economic lot sizing problem with product returns and recovery

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ABSTRACT

The economic lot sizing problem with product returns and recovery is an important problem that appears in reverse logistics, and has recently been proved to be NP-hard. In this paper, we suggest a variable neighborhood search (VNS) metaheuristic algorithm for solving this problem. It is the first time that such an approach has been used for this problem in the literature. Our research contributions are threefold: first, we propose two novel VNS variants to tackle this problem efficiently. Second, we present several new neighborhoods for this combinatorial optimization problem, and an efficient local search method for exploring them. The computational results, obtained on a recent set of benchmark problems with 6480 instances, demonstrate that our approach outperforms the state-of-the-art heuristic methods from the literature, and that it achieved an average optimality gap equal to 0.283% within average 8.3 s. Third, we also present a new benchmark set with the largest instances in the literature. We demonstrate the robustness of the proposed VNS approach in this new benchmark set compared with Gurobi optimizer.

1. Introduction

Reverse logistics stands for all operations related to the return of products and materials. It is a process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished products and related information from the point of consumption to the point of origin for the purpose of recovery value or proper disposal. Reusing product, or material returns have gained considerable attention in industry and academia because of economical, environmental and legislative reasons. Balancing economic development with environmental protection is a key challenge to sustain manufacturing companies. Conventional manufacturing is unsustainable because of its significant adverse environmental impacts. Remanufacturing can help companies to achieve sustainable manufacturing by saving costs via reductions in consumption of natural resources. Remanufacturing can also help to reduce environment burden by decreasing landfill wastes and reclaim resources and energy already consumed in the original manufacturing of the products. Besides the environmental benefits, remanufacturing also provides economic incentives to companies by selling the remanufactured products and extending the life cycles of the products (Geyer et al., 2007).

Remanufacturing transforms used products into like new ones. After disassembly, sorting and cleaning, modules and parts are extensively inspected and problematic parts are repaired, or if not possible, replaced by new parts (Ijomah, 2002). These operations allow a considerable amount of value incorporated in the used product to be regained. Remanufactured products have usually the same quality as the new products and are sold for the same price, but they are less costly. The significance of remanufacturing is that it would allow manufacturers to respond to environmental and legislative pressure by enabling them to meet waste legislation while maintaining high productivity for high-quality, lower-cost products with less landing filling and consumption of raw materials and energy (Lund, 1984).

Inventory management and control is one of the key decision making areas while managing product returns and remanufacturing. A scientific literature review of the existing quantitative models on inventory control with product returns and remanufacturing can be found in the recent work of Akcali and Cetinkaya (2011). The Dynamic or Economic Lot Sizing Problem (DLSP or ELSP) is one of the most extensively researched topics in inventory control literature. ELSP considers a warehouse or retailer facing a dynamic and deterministic demand for a single item over a finite

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horizon (Wagner and Whitin, 1958). A lot of research has been done on dynamic lot sizing since late 1950s after the seminal paper (Wagner and Whitin, 1958). For a general review of the economic lot sizing problem, readers may refer to Brahimi and Dauzere-Peres (2006) and Buschkühl et al. (2010). The ELSP with remanufacturing options (ELSRP) is an extension of the classical Wagner Whitin model. The additional feature is that in each period known quantities of used products enter the system. These returns can be remanufactured to satisfy demand besides regular manufacturing. This means that there are two types of inventory: the inventory of returns and the inventory of serviceables, where a serviceable is either a newly manufactured item or a remanufactured returned item. In ELSR problem, the traditional trade-off between set-up and holding costs is extended with remanufacturing set-up cost and holding cost for returns.

Many different variants of the ELSR problem, described above, have been studied. Richter and Sombrutzki (2000) extended the classical Wagner–Whitin model by introducing remanufacturing process. They assumed that the dynamic demand could be satisfied from two sources: newly produced items, and the used ones, returned to the system, stored and remanufactured. They presented a dynamic programming algorithm to determine the periods in which products are manufactured and remanufactured. Richter and Weber (2001) introduced a reverse Wagner–Whitin model with variable manufacturing and remanufacturing costs. They also investigated the behaviour of the system with a disposal option. Golany et al. (2001) studied a variant of ELSRP with deterministic demand and return setting in the presence of disposal options and provided a polynomial solution algorithm. Yang et al. (2005) extended the work by Golany et al. (2001) on the concave cost functions. Based on a special structure of the extreme-point optimal solutions for the minimum concave cost problem, they developed a polynomial-time heuristic algorithm. Beltran and Krass (2002) studied the case where demand can be satisfied by new items and unprocessed returned items, and the returned items can also be disposed. They proposed some useful properties of the optimal solution (manufacturing and disposal decisions) which led to a dynamic programming algorithm. Pineyro and Viera (2009) proposed and evaluated a set of inventory policies designed for the ELSRP under the assumption that remanufacturing the used items is more suitable than disposing them and producing new items. Teunter et al. (2006) presented two variants of the basic dynamic lot sizing model with product returns. In the first model variant, it is assumed that there is a joint set up cost for manufacturing and remanufacturing when the same production line is used for both processes, and the second model variant assumed separate set up costs for manufacturing and remanufacturing when separate production lines are used. For these two models, several heuristic algorithms were proposed and compared with the computational performance of modified versions of three well-known heuristics, namely Silver-Meal (SM), Least Unit Cost, and Part Period Balancing. Teunter et al. (2009) later advanced the study of the ELSRP by developing fast but simple heuristics that can provide near-optimal solutions. Schulz (2011) proposed a generalization of the Silver-Meal based heuristic introduced by Teunter et al. (2006) for the separate set up cost setting by using known results of the static lot sizing problem.

Recently, Nenes et al. (2010) studied some inventory control policies for inspection and remanufacturing and proposed alternative policies when both demand of new products and returns of used products are stochastic; Helmrich et al. (2014) added some valid inequalities to the original formulation of the ELSRP to improve its formulation, and also presented reformulations based on the shortest path problem for the ELSR problem. Also, Pineyro and Viera (2010) extended the ELSR problem for the case where substitution is allowed for remanufactured items.

Tang and Teunter (2006) studied the multi-product dynamic lot sizing problem for a hybrid production line with manufacturing new products and remanufacturing the returned products. They considered one manufacturing and one remanufacturing lot for each product during a common cycle time and formulated a Mixed Integer Linear Programming (MILP) problem to find an exact solution. The multi-product dynamic lot sizing problem with two production sources, manufacturing and remanufacturing, for which operations are performed on separate dedicated lines was studied in Teunter et al. (2008). The authors proposed a mixed integer programming model to solve the problem for a fixed cycle time, which can be combined with a cycle time search to find an optimal solution. In Zanoni et al. (2012), the multi-product ELSRP was further analyzed, extending the scheduling policy from the common cycle to a basic period policy. They relaxed the constraint of one manufacturing lot and one remanufacturing lot for each product during a common cycle time studied in Tang and Teunter (2006), and they proposed an algorithm to solve their model.

Recently, both trajectory-based and population-based metaheuristics were used to tackle the ELSR problem. Pineyro and Viera (2009) suggested a Tabu Search procedure for solving the problem tackled, even with a more general cost structure and final disposing of returns. Li et al. (2014) also developed a Tabu Search (TS) algorithm based on an alternative mixed-integer linear programming formulation. The TS algorithm solves the problem of several small linear sub-problems of the original model. Moustaki et al. (2013) studied the behavior of Particle Swarm Optimization (PSO) algorithm on the ELSR problem. The most suitable variants of the algorithm were identified, and the necessary modifications in the formulation of the corresponding optimization problem were provided. The performance of the above two metaheuristic algorithms were compared with the Silver-Meal based heuristics, proposed by Schulz (2011), in each of the above papers, and showed that the proposed algorithms can be considered as a promising alternative for solving ELSR problem. In a very recent paper (Baki et al. (2014)), the authors proved that the ELSR problem is NP-hard, and they constructed a heuristic method that uses dynamic programming and the Wagner–Whitin algorithm to solve the problem.

In this work, we propose two novel variants of the variable neighborhood search (VNS) algorithm to find the optimal solution for the ELSR problem, and also we assess their performance first on the test suite used by Schulz (2011), and second on a new benchmark set with more than four times larger instances. The proposed VNS approach is also compared with the established SM-based variants from Schulz (2011) and other metaheuristics optimization algorithms. Although VNS has also been applied to other inventory problems (AlmadaLobo and James, 2010; Almada-Lobo et al., 2008; Xiao et al., 2011a,b, 2014), this is the first time that it is used for this particular problem.

1.1. Research contributions

The research contributions of this paper are as follows:

- Two novel VNS schemes are proposed for the first time and tested for this combinatorial optimization ELSR problem. The methodological contribution is based on the fact that the proposed VNS approaches use new strategies for the local search and also for the shaking phase.
- Several new neighborhoods for this combinatorial optimization problem are presented and an efficient local search method for exploring them is described.
- The computational results obtained on an established set of benchmark problems with 6480 instances show that our VNS metaheuristic algorithm outperforms the state-of-the-art heuristic methods from the literature, and that it is able to achieve an average optimality gap equal to 0.283% within average 8.3 s.

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